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Quantative Spectroscopy of X-Ray Laser Plasmas in Pulsed Power Devices

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Final Report

In the first year of this research program the first version of a small z-pinch discharge was designed and constructed. Some preliminary studies of the discharge were made using a framing camera, a visible spectrometer and a VUV spectrometer. A quadrature interferometer was designed and its constituent parts were procured.

Construction of the latter diagnostic was finished in the second year of the program. Estimates of the electron density obtained side-on, with the interferometer, and end-on, from VUV measurements of line widths, gave n_e to be at most roughly $10^{17} cm^{-3}$. In an effort to augment this density and to obtain a more classical type of z-pinch behaviour a second version of the discharge was designed and constructed. A framing camera study of this discharge confirmed the expected behaviour and further demonstrated the presence of an unacceptable degree of cylindrical asymmetry. End-on VUV spectra revealed the absence of all lines below roughly 800 A. At the end of the second year a third design for the discharge was undertaken and its construction was started.

In the final year construction of the third version of the discharge was completed. A set of diagnostic measurements was then undertaken. These diagnostics consisted of a framing camera, a photodiode, a 1 m N.I. VUV spectrometer and a Rogowski coil.

An initial framing camera study of the visible signature of the plasma was made for various differing conditions such as fill gas, fill pressure, charging voltage. This revealed some of the gross features of the discharge. In contrast to the case of the cross shaped discharge vessel, the new setup resulted in the formation of a linear, cylindrically symmetric, visually uniform plasma on axis at peak compression, subject to sausage instability under most conditions. Volume compression ratios of over a hundred were typical. Absence of sausage instability and its attendant breakup of the plasma was noted for the special case when the conditions were tailored for the coincidence of the timing of maximum compression and that of the zero current at the end of the first current half cycle. This latter form of the plasma evolution promised to be the most ideal for the observation of gain. However, because of the long current half cycle time ($3\mu s$ - $5\mu s$) and hence long time to maximum compression that this form demanded, the temperature of these plasmas proved to be far cooler than that needed to produce the CV neccessary for recombination.

Further working knowledge of the discharge was obtained by means of a study of the timing of peak pinch compression as a function of several parameters : fill gas, fill pressure and charging voltage. The study was carried out using a photodiode whose signal signature had been correlated with framing camera photographs. This study established an empirical set of power laws for time to maximimum compression vs. mass loading and charging voltage for a variety of fill gasses (Hydrogen, Helium, Argon and methane). This knowledge would prove an essential factor when tailoring the discharge conditions while retaining control of the pinch electron temperature.

A series of time integrated VUV spectra were taken in hydrogen and methane in both end-on and side-on geometries. At higher fill pressures (100 mTorr and above) spectra in both gasses and in both geometries displayed a cutoff of light below 800 A. This phenomenon had been observed on the previous discharge setup and with a different instrument. Prior to this we suspected that this was due to a problem with the detector or with the grating. However, with the new setup at lower fill pressures (30 mtorr) and only for the side-on geometry, spectra below 800 A were observed in Hydrogen. This observation has led to the conclusion that molecular absorption by molecules and radicals in the gasses was responsible for the extinction of the light below 800 A at higher fill pressures. Analysis of a spectrum taken end-on in Hydrogen suggested that two distinct plasmas were present, a hot pinch plasma on axis responsible for observed lines of SiIV, NV and OV and a cooler carbon plasma in the neighbourhood of the electrodes responsible for observed lines of CII and CIII. These results were presented as a poster at the November 1989 Division of Plasma Physics meeting.

Finally the line shapes of several transitions in CIV (the 3d-2p line at 384 A in 2nd order at 768 A, 5f-3d at 800 A and 4f-3d at 1169 A) at maximum compression were recorded using the 1 m N.I. VUV instrument in monochromator mode with a side-on geometry. These shots were taken in a 50 mTorr methane fill with a 9 μF capacitor bank charged to 17.5 kV. The 3d-2p line was particularly strong and gave an excellent signal to noise ratio with acceptable shot to shot variation. The FWHM of the line was estimated to be 0.5 A (in first order). The other lines were much weaker with appreciable noise and shot to shot variations particularly for the 5f-3d 800 A line. The FWHM of the 4f-3d line was estimated to be 3.5 A, with only a very rough estimate of 4 A possible for the 5f-3d line.

These broad lines if interpreted in terms of Stark broadening suggested electron densities of over $10^{18} cm^{-3}$, perhaps slightly high for significant population inversions and gain. However, actual densities are believed to be smaller and will be measured interferometrically in future work. The 3d-2p line width is probably significantly enhanced by opacity effects.

We have also considered the effects of stimulated radiative processes on the spectral line shapes, developing an iterative self-consistent procedure for dealing with the line shape and radiation transport problems. Some of this research has already been published,[1] and we have presented some additional results at the APS Plasma Division meeting last fall.

Returning to the experimental program, we hope additionally to be able to undertake the originally proposed work on capillaries, which may indeed provide a gain medium at 180 A.[2]

References

[1] H. R. Griem, *Effects of stimulated radiative processes on spectral structure of amplified spontaneous emission*, Phys. Rev. A **40** 3706 (1989).

[2] C. Steden and H. J. Kunze, *Observation of Gain at 18.22 nm in the Carbon Plasma of a Capillary Discharge*, preprint.